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Rapid Hot Dog Surface Pasteurization Using Cycles of Vacuum and Steam To Kill *Listeria innocua*†

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ABSTRACT

The vacuum/steam/vacuum surface pasteurization process was applied to hot dogs inoculated on the surface with nonpathogenic *Listeria innocua*. Using the optimum conditions previously found for processing chicken carcasses as a starting point, optimum process conditions were determined for a hot dog treatment compatible with current process line speed. Cycling the treatment significantly improved the microbiological kill. At the optimum conditions of steam time of 0.3 s at 138°C (two cycles), a bacteria kill >3 log CFU/ml was attained. Pasteurization, frequently considered to be a kill of >5 log CFU/ml, was reached by increasing the number of cycles to three. The surface pasteurization process should ensure that hot dogs reaching the consumer are free of *Listeria*.

The food industry is experiencing ever-increasing media reports of foodborne disease. Recently, the reports of outbreaks concerned ready-to-eat meats. Numerous recalls have been conducted because of *Listeria monocytogenes* contamination of hot dogs and lunch meats *(2, 3, 7)*.

From early August 1998 through January 6, 1999, the Centers for Disease Control and Prevention reported approximately 100 illnesses in 22 states caused by *L. monocytogenes* serotype 4b. Twenty-one deaths, 15 adults and 6 miscarriages or stillbirths, were reported. The Centers for Disease Control and Prevention and state and local health departments identified the vehicle for transmission as hot dogs and possibly deli meats *(1, 5, 6)*.

Hot dogs should be free of *Listeria* contamination when exiting the cooker. Removal of the casing and atmospheric contamination exposes the product to *Listeria* after cooking and before packaging. According to industry sources (personal communication), this contamination is on the surface; therefore, it should be amenable to surface pasteurization. Additional scientific investigation is required to rule out nonsurface contamination.

Morgan et al. *(13)* presented an excellent discussion of the theory behind the vacuum/steam/vacuum (VSV) surface-pasteurization process. In brief, steam is capable of killing pathogens. However, air and water on the surface of the product act as insulation *(12, 15)*. (Although water is a good conductor of thermal energy, relative to steam, it acts as insulation.) Exposing the product to steam for a time sufficient to transfer the energy across the air/water barrier to destroy bacteria thermally damages the surface. The process of VSV surface pasteurization uses a short exposure to vacuuming to remove these insulating fluids. This is followed by a quick burst of condensing steam, which rapidly transfers the energy directly to the bacteria. Then, a second exposure to vacuuming cools the meat (through evaporation), preventing thermal damage. The process time is on the order of 1 to 2 s.

A prototype surface pasteurizer was designed, fabricated, and patented *(11, 13)*. Experiments using this prototype showed that the process reduces bacteria on fresh, raw chicken pieces by 2 to 3 logs, depending on the type of piece *(10, 14)*. For instance, bacteria kills were greater on drumsticks than on breast meat. Additional research led to three improved versions. Using the latest unit, the fourth, feasible processing conditions for chicken surface treatment were developed *(9)*.

The objective of this research was to develop a process to rapidly pasteurize the surface of hot dogs.

MATERIALS AND METHODS

Mechanical design of VSV surface pasteurizer. The surface pasteurizer was designed to process chicken carcasses, specifically broilers. The performance requirements of a surface pasteurizer for chicken are (i) to accept carcasses individually and to enclose them in a chamber within a rotor, (ii) to evacuate that chamber, (iii) to treat the carcass in the closed chamber with steam, (iv) to cool the carcass with a vacuum, and (v) to eject the carcass into a clean environment. The simplest design, one chamber in one rotor, was designed and constructed. Figure 1 is a schematic diagram of the processor, and Figure 2 shows the details of the product treatment section. A cylindrical chamber for a broiler carcass should be about 200 mm in diameter and 240 mm deep. Such a chamber is provided by a 203-mm ball valve. The same cylindrical chamber (product valve) was used to treat individual hot dogs. Obviously, a different product valve would be used in a machine designed to treat hot dogs instead of chicken carcasses.

To admit vacuum or steam into the closed chamber, two op-

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† Mention of brand or firm names does not constitute an endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

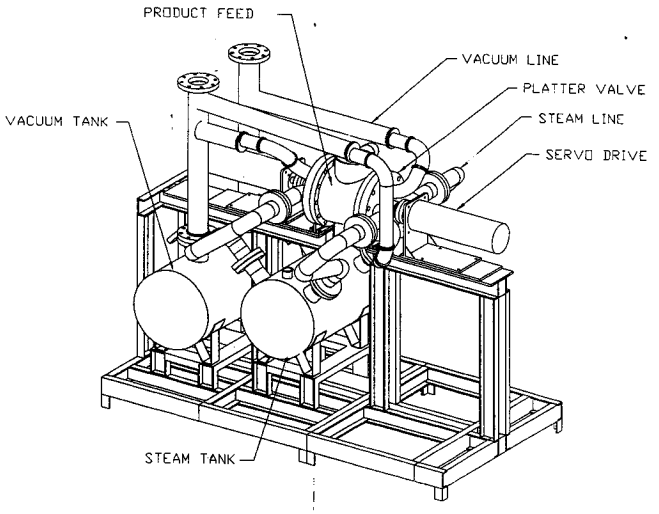

FIGURE 1. *Schematic diagram of the prototype VSV surface pasteurizer.*

posed 200-mm holes were bored through the stator at right angles to both the axis of rotation of the ball and to the centerline of the open chamber. Two gas valves are coupled closely to these 200-mm ports; each consists of a flat disk rotating against an inlet header, which holds polyetheretherketone seals. Each disk contains two holes, which, when stopped at one of the ports in the inlet header, permit gas to flow into the treatment chamber. Multiple holes reduce the angular movement of the rotor, which is necessary for valve action, and increase the cross-sectional area for gas flow. Each disk is programmed independently and is moved by its own servo motor. The servos were 50-J units capable of high acceleration and deceleration.

To expose all exterior surfaces of the test specimen to treatment, a screen was installed at the midpoint of the product valve to hold the sample. The steam generator was charged with deionized water and boiled for 30 min for deaeration. The vacuum receiver was adjusted to 70 mbar, and its condenser coil was cooled to 4°C.

Operation of VSV surface pasteurizer. Each hot dog sample was manually inserted into the treatment chamber of the surface pasteurizer. The ball valve was rotated, with a servo, 90 degrees to seal the chamber from the outside atmosphere. Operation of the ball valve was controlled by computer. The platter valves rotated to expose the sample to vacuum, then steam, and then vacuum again. With multiple cycles, the sequence of vacuum then steam was repeated multiple times. Process variables were vacuum times, steam temperature, time, and number of cycles.

After treatment, the ball valve rotated back 90 degrees to expose the sample to atmosphere. The hot dog sample was aseptically removed manually after treatment.

Preparation of hot dogs. Hot dogs were purchased at local large metropolitan supermarkets with high inventory turnover. They were purchased fresh and used within 1 week, well within the recommended use period. Hot dogs were inoculated with *Listeria innocua,* which was chosen because it is nonpathogenic and has a resistance similar to or higher than that of *L. monocytogenes (16).* Using a loopful of *L. innocua* taken from a refrigerated slant, the inoculum was grown and placed in 100 ml of bovine calf brain-heart infusion broth supplemented with 3% glucose. The inoculum was incubated overnight at 28°C. The amount of inoculum and contact and drain times were chosen by trial and error

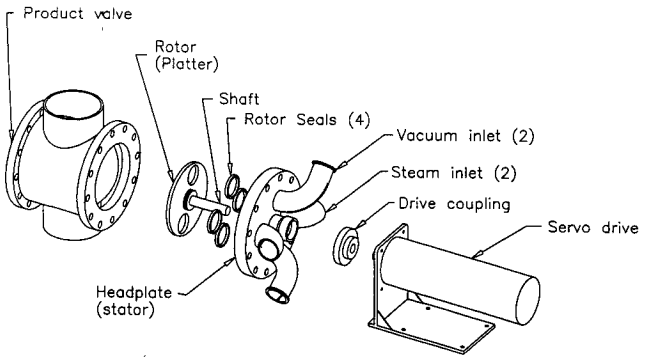

FIGURE 2. *Details of the product treatment section of the prototype VSV surface pasteurizer.*

to have sufficient bacteria attached on the hot dog. The hot dogs were inoculated by dipping into a container with 10^6 CFU of *L. innocua* per ml for a contact time of 10 min. This procedure was previously found (unpublished data) to give high surface counts when inoculating chicken. Upon removal, the hot dogs were allowed to drain for 30 min before experimentation. The 30-min drain time was selected because the process time for hot dogs from exit of the cooker until packaging can frequently reach 30 min. Also, by 30 min, the excess surface liquid had drained and dried.

Microbiological testing. To determine *L. innocua* counts after processing in the pasteurizer, the hot dog samples were placed in sterile plastic bags with Butterfield buffer solution (Difco Laboratories, Detroit, Mich.), 1 hot dog per 50 ml of buffer, and manually rinsed for 60 s (shaken 60 times). The hot dog rinses were appropriately diluted with 1% peptone water in 9.9 ml of rinse solution, sterilized by autoclaving, and plated onto Tryptose agar (Difco) using a spiral plater. Plates were incubated at 37°C for 1 day. Colonies were counted and expressed as colony-forming units per milliter. Because the hot dogs were usually initially sterile, it was usually unnecessary to differentiate *Listeria* from interfering background flora. However, a template was available to ensure that only *Listeria* were counted. To convert colony-forming units per milliliter to colony-forming units per hot dog, simply multiply the colony-forming units per milliter by 50 (CFU/ml × 50 ml per hot dog). Noninoculated control samples contained no detectable *Listeria* (detection limit, 0.60 log CFU/ml).

Process optimization. For optimization studies, 2^3 factorial experimental designs *(8)* were used (Tables 2 through 4). Treatment samples consisted of four replicates. Data from the factorial designs were analyzed by analysis of variance using the replicate within-treatment terms as error terms. Control samples of inoculated hot dogs were taken to provide an independent estimate of the extent of bacteria kill. A null hypothesis *(17)* was made on the difference between means (H_0; $\text{mean}_1 = \text{mean}_2$) to compare mean bacteria counts at 126 and 138°C.

RESULTS AND DISCUSSION

Previous research with chicken carcasses determined the following optimum process parameters: initial vacuum time, 0.1 s; steam time, 0.1 s; steam temperature, 126 to 138°C; and final vacuum time, 0.3 to 0.5 s *(9).*

The following initial process parameters for hot dogs were chosen: initial vacuum time, 0.1 s; final vacuum time, 0.5 s; and steam time, 0.1 s. The steam temperature was set to two levels, 126 and 138°C. There was a statistically

TABLE 1. *Initial process trials for hot dogs*[a]

	Temperature					
	126°C			138°C		
Trial	*L. innocua* (log CFU/ml)	SD	*n*	*L. innocua* (log CFU/ml)	SD	*n*
Control	3.71	0.055	15	3.97	0.072	14
Treatment	1.98	0.183	10	1.58	0.233	13
Kill	1.73	0.183	10	2.39	0.233	13

[a] Initial vacuum time was 0.1 s; final vacuum time, 0.5 s; and steam time, 0.1 s.

significant difference between the mean bacteria counts and kill after treatment at the two temperatures, as shown in Table 1. The bacteria kill at 138°C, 2.39 log CFU/ml, was significantly greater than that at 126°C, 1.73 log CFU/ml. Therefore, 138°C was used for the rest of the studies on hot dogs. (Higher steam temperatures may give even better bacteria kills; however, there is the possibilty that this process could be commercialized for hot dogs at the packaging line where there would be the possibility of higher tempertures melting the packaging film. The temperature was kept at 138°C to prevent damage to packaging materials.)

The optimum conditions for chicken treatment were constrained by the requirement that the chicken exhibit virtually no evidence of cooking. Hot dogs are already cooked, so this constraint is greatly relaxed. However, it is still necessary to prevent thermal damage to the product. The hot dogs exhibited no change in appearance in this study.

Air and water form a film on the surface of the product. The film interferes with rapid energy transfer from the steam to the hot dog. Although the interfering surface layers are removed with the initial application of vacuuming, the condensing steam itself continuously deposits an insulating water (condensate) layer during processing. Cycling between the vacuum and steam steps should effectively remove this redeposited water layer as soon as it forms and improve surface treatment.

Steam exposure time was studied in two ways. First, steam time was varied from 0.1 s to 0.5 s in one cycle. Second, the number of cycles was varied, using 0.1 s per cycle. The total steam exposure time was varied from 0.1 to 0.5 s and was calculated as the number of cycles multiplied by 0.1 s per cycle. Figure 3 plots the bacteria counts after treatment versus total exposure time.

Varying the steam exposure time and using one cycle resulted in minimum survival of bacteria at 0.3 s. By using cycling and a steam exposure time of 0.1 s per cycle, the bacteria count was reduced to below the detection limit at 0.2 and 0.3 s of total steam exposure time. Cycling produced a lower count at the same total steam exposure time.

A series of three 2^3 factorial experimental designs was made to determine optimum processing conditions for hot dogs (Tables 2 through 4). Optimization was performed in the vicinity of the apparent optimum values mentioned above, namely, vacuum times of 0.3 to 0.5 s, steam times of 0.1 to 0.4 s, and cycling of vacuum and steam.

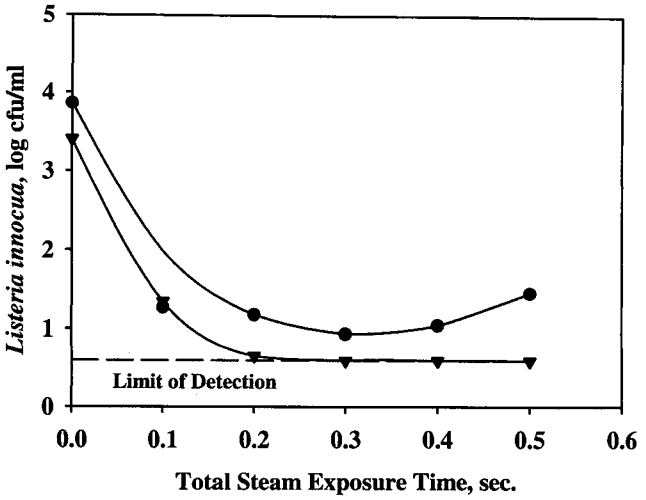

FIGURE 3. *Effect of steam cycle time and steam exposure time on* L. innocua *present on the surface of hot dogs.* ●, *one cycle with different steam exposure times;* ▼, *multiple cycles of 0.1 s per cycle.*

In all three designs, the intermediate and final vacuum steps were set at 0.3 and 0.5 s, respectively, and the number of cycles was set at 1 or 2. In the first 2^3 factorial experimental design (Table 2), the steam time was set at 0.1 or 0.2 s per cycle. The only variable that was significant was number of cycles. Two cycles were significantly better than one cycle. The mean *L. innocua* count of the control samples (n = 10) was 3.67 log CFU/ml (SD = 0.094 CFU/ml). The mean count of the experimental samples (n = 32) was 0.99 log CFU/ml (SD = 0.405 CFU/ml).

In the second experimental design (Table 3), the steam time was 0.2 and 0.3 s per cycle. (Figure 3 indicated this to be the optimum process range.) The only statistically significant variable was number of cycles. Two cycles were better than one. Steam time and vacuum time variables were possibly significant ($P \leq 0.10$). The longer steam

TABLE 2. *2^3 factorial experimental design and results of analysis of variance for hot dogs, steam times of 0.1 and 0.2 s*

Experimental design[a]			Analysis of variance[a]		
Factor	−	+	Source	*L. innocua* mean square value	F^b
A	0.1	0.2	A	0.021	0.3
B	1	2	B	2.526	31.8**
C	0.3	0.5	AB	0.009	0.1
			C	0.503	6.3*
			AC	0.064	0.8
			BC	0.012	0.2
			ABC	0.041	0.5
			Error	0.080	

[a] A, steam time (s); B, number of cycles; C, between-cycle and final vacuum times (s). Steam temperature was 138°C. Treatment samples consisted of four replicates.

[b] *$P \leq 0.05$; **$P \leq 0.01$.

TABLE 3. *2^3 factorial experimental design and results of analysis of variance for hot dogs, steam times of 0.2 and 0.3 s*

Experimental design[a]			Analysis of variance[a]		
Factor	−	+	Source	*L. innocua* mean square value	F^b
A	0.2	0.3	A	0.189	4.2*
B	1	2	B	3.001	66.5**
C	0.3	0.5	AB	0.041	0.9
			C	0.140	3.1*
			AC	0.0003	0.01
			BC	0.020	0.4
			ABC	0.00001	0.00
			Error	0.045	

[a] A, steam time (s); B, number of cycles; C, between-cycle and final vacuum times (s). Steam temperature was 138°C. Treatment samples consisted of four replicates.
[b] $*P \leq 0.10$; $**P \leq 0.01$.

time, 0.3 s, was better, as was the shorter vacuum time, 0.3 s. The mean *L. innocua* count of the control samples (n = 10) was 3.71 log CFU/ml (SD = 0.155 CFU/ml). The mean count of the experimental samples (n = 32) was 0.99 log CFU/ml (SD = 0.380 CFU/ml).

Table 4 extended the investigation to 0.3 and 0.4 s of steam time. Number of cycles was highly significant. The only other significant variable was the BC interaction (number of cycles by vacuum time). The mean *L. innocua* count of the control samples (n = 10) was 3.63 log CFU/ml (SD = 0.210 CFU/ml). The mean count of the experimental samples (n = 32) was 0.99 log CFU/ml (SD = 0.430 CFU/ml).

On the basis of these results, two cycles with 0.3 s of steam exposure time per cycle were chosen as optimum conditions. Vacuum time, both final and between cycles, was chosen as 0.3 s. With these conditions, the total process time is 1.3 s.

TABLE 4. *2^3 factorial experimental design and results of analysis of variance for hot dogs, steam times of 0.3 and 0.4 s*

Experimental design[a]			Analysis of variance[a]		
Factor	−	+	Source	*L. innocua* mean square value	F^b
A	0.3	0.4	A	0.056	1.1
B	1	2	B	4.090	80.9**
C	0.3	0.5	AB	0.005	0.1
			C	0.099	2.0
			AC	0.001	0.0
			BC	0.235	4.6*
			ABC	0.042	0.8
			Error	0.051	

[a] A, steam time (s); B, number of cycles; C, between-cycle and final vacuum times (s). Steam temperature was 138°C. Treatment samples consisted of four replicates.
[b] $*P \leq 0.05$; $**P \leq 0.001$.

TABLE 5. *Confirmation of optimum region[a]*

No. cycles	Steam time/ cycle (s)	*L. innocua* (log CFU/ml)	SD	Kill (log CFU/ml)	Total process time (s)
Control		3.85	0.032		
1	0.3	1.24	0.274	2.61	0.8
2	0.3	0.60		3.25	1.3
3	0.1	0.60		3.25	1.3

[a] Steam temperature was 138°C. Initial vacuum time was 0.1 s; and between-cycle vacuum time, 0.3 s. Control samples included 10 replicates; treatment samples included 5 replicates.

Table 5 lists results of three experiments conducted to confirm the choice of optimum conditions. With a steam time of 0.3 s per cycle, one and two cycles were used. Two cycles were significantly ($P \leq 0.05$) better than one cycle. The total process time for two cycles was 1.3 s. Using three cycles and a steam exposure time of 0.1 s per cycle, the same result was achieved. Total process time was 1.3 s. This confirms the choice of two cycles as optimum with 0.3 s of steam exposure per cycle.

The experiments described in Table 5 were run with *L. innocua* inoculum levels of approximately 3 log CFU/ml. Optimum conditions reduced bacteria counts below the detection limit. These conditions indicate the possibility of achieving a 5 log kill on hot dogs, which is frequently considered as indicative of pasteurization *(4)*.

In the study described in Table 6, the inoculum level was increased to increase the counts on control samples to detect a 5 log kill (pasteurization). Control sample counts were 5.2 log CFU/ml. The number of cycles and steam time were varied. With the higher inoculum level, increasing the number of cycles to three or four and the steam time to 0.4 s per cycle reduced the bacteria count from 5.2 log CFU/ml to below the detection limit of 0.60 log CFU/ml, which is approximately a 5 log kill. The experiments described in Table 6 were repeated with an even higher inoculum level to detect kills in excess of 5 log over the detection limit.

TABLE 6. *Pasteurization of hot dogs[a]*

No. cycles	Steam time/ cycle (s)	*L. innocua* (log CFU/ml)	SD	Kill (log CFU/ml)	Total process time (s)
Control		5.19	0.124		
2	0.3	0.92	0.274	4.27	1.3
3	0.3	0.93	0.537	4.26	1.9
4	0.3	0.77	0.330	4.42	2.5
2	0.4	1.24	0.520	3.95	1.5
3	0.4	<0.60		>4.59	2.2
4	0.4	<0.60		>4.59	2.9

[a] Steam temperature was 138°C. Initial vacuum time was 0.1 s; and between-cycle vacuum time, 0.3 s. Control samples included five replicates; treatment samples included four replicates.

TABLE 7. *Confirmation of pasteurization of hot dogs*[a]

No. cycles	Steam time/ cycle (s)	*L. innocua* (log CFU/ml)	SD	Kill (log CFU/ml)	Total process time (s)
Control		6.18	0.040		
2	0.3	2.00	0.207	4.18	1.3
3	0.3	1.16	0.427	5.03	1.9
4	0.3	0.65	0.090	5.54	2.5
2	0.4	1.78	0.620	4.40	1.5
3	0.4	1.85	0.921	4.33	2.2
4	0.4	1.25	0.607	4.93	2.9

[a] Steam temperature was 138°C. Initial vacuum time was 0.1 s; and between-cycle vacuum time, 0.3 s. Control samples included four replicates; treatment samples included four replicates.

The results listed in Table 7 show that a >5 log kill was achieved with three or four cycles and steam time of 0.3 s per cycle.

CONCLUSIONS

The optimum processing conditions for hot dogs that are compatible with normal packaging line speed are (i) an initial vacuum time of 0.1 s, (ii) a steam time of 0.3 s per cycle at a steam temperature of 138°C, and (iii) final and between-cycle vacuum times of 0.3 s. Using two cycles, the VSV surface pasteurizer reduces the *L. innocua* count on hot dogs from 3 log CFU/ml to below the detection limit of 0.6 log CFU/ml. Pasteurization, i.e., a 5-log decrease in the level of *L. innocua,* can be achieved by increasing the number of cycles to three or four with a corresponding increase in process time. The hot dogs were visually unchanged.

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